

Space-Based Gravitational-Wave Observations as Tools for Testing General Relativity

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Principal Investigator: Clifford M. Will
Department of Physics, Washington University
One Brookings Drive, St. Louis MO 63130

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1 Introduction

We continued a project to analyse the ways in which detection and study of gravitational waves could provide quantitative tests of general relativity, with particular emphasis on waves that would be detectable by space-based observatories, such as LISA. This work had three foci:

- Tests of scalar-tensor theories of gravity that could be done by analyzing gravitational waves from neutron stars inspiralling into massive black holes, as detectable by LISA.
- Study of alternative theories of gravity in which the graviton could be massive, and of how gravitational-wave observations by space-based detectors, solar-system tests, and cosmological observations could constrain such theories.
- Study of gravitational-radiation back reaction of particles orbiting black holes in general relativity, with emphasis on the effects of spin.

2 Testing Alternative Theories of Gravity Using Space Gravitational-wave Interferometers

We calculated the bounds which could be placed on scalar-tensor theories of gravity of the Jordan, Fierz, Brans and Dicke type by measurements of gravitational waveforms from neutron stars (NS) spiralling into massive black holes (MBH) using LISA, the proposed space laser interferometric observatory [1]. We found that such observations may yield more stringent bounds on the Brans-Dicke coupling parameter ω than are achievable from solar system or binary pulsar measurements (in the limit $\omega \rightarrow \infty$, scalar-tensor theories approach general relativity).

We extended this work and earlier work by Will [2] by considering, in addition, bounds that could be placed on the Compton wavelength of the “graviton” in hypothetical “massive graviton” theories of gravity, using measurements of gravitational waveforms from binary massive black hole inspiral using LISA [3]. We made use of improved noise curves for LISA that have been established by the LISA International Science Team, and that are available online [4]. The hypothetical bounds on the Brans-Dicke coupling parameter and on the Compton wavelength of the graviton were found to be comparable to those found earlier [1, 2].

We then incorporated the effects of aligned spins, and studied the degradation in accuracy that would result, both in testing alternative theories and in measuring parameters such as chirp mass and reduced mass of the bodies. We also carried out Monte Carlo simulations of 10,000 binaries distributed over the sky in order to study the accuracy of parameter estimation and theory testing, as well as the angular resolution and distance accuracy, when the angular dependence and orbital motion of the LISA instrument are included [5]. This work was carried out with current post-doctoral fellow Emanuele Berti, in collaboration with Alessandra Buonanno (Institut d’Astrophysique de Paris).

3 Gravitational-wave detection and LISA

We estimated the rate at which LISA could detect intermediate-mass black-hole binaries, that is, binaries containing a black hole in the mass range $10 - 100 M_{\odot}$ orbiting a black hole in the mass range $100 - 1000 M_{\odot}$ [6]. For one-year integrations leading up to the innermost stable orbit, and a signal-to-noise ratio of 10, we estimated a detection rate of only 1 per million years for $10M_{\odot}/100M_{\odot}$ binaries. The estimate used the online LISA noise curve, and improved upon earlier estimates by Miller [7]. We also showed that, while all IMBH systems in this mass range may be detected in the Virgo cluster up to 40 years before merger, none can be detected there earlier than 400 years before merger.

4 Gravitational radiation back-reaction: effects of spin

We completed an analysis of the effects of spin on the gravitational radiation reaction of inspiralling binary systems, in the post-Newtonian approximation. We worked in an approximation that includes the first-post-Newtonian effects at order $(v/c)^2$, and the effects of radiation reaction at orders $(v/c)^5$ and $(v/c)^7$. This is sufficient to calculate the leading effects of spin. We found that radiation reaction has no effect on the individual spins to the order considered, and that the equations of motion yielded expressions for orbital energy and total angular momentum loss that match precisely formulae for energy and angular momentum flux in gravitational radiation, including spin-orbit terms [8, 9]. This work is being written up for publication [10]. The resulting equations of motion will be applicable to the study of compact objects inspiralling into massive spinning (Kerr) black holes, an important class of sources for LISA.

5 Bibliography

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